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A model for representing the Italian energy system: The NEEDS-TIMES experience

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Abstract

Sustainability of energy systems has a strategic role in the current energy-environmental policies as it involves key issues such as security of energy supply, mitigation of environmental impact (with special regard to air quality improvement) and energy affordability. In this framework modelling activities are more than ever a strategic issue in order to manage the large complexity of energy systems as well as to support the decision-making process at different stages and spatial scales (regional, national, Pan-European, etc.). The aim of this article is to present a new model for the Italian energy system implemented with a common effort in the framework of an integrated project under the Sixth Framework Programme. In particular, the main features of the common methodology are briefly recalled and the modelling structure, the main data and assumptions, sector by sector, are presented. Moreover the main results obtained for the baseline (BAU) scenario are fully described.

Keywords: Decision-making tools; Energy system analysis; Modelling of energy systems; NEEDS-TIMES models

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1. Introduction

Sustainability of energy systems has become in recent years a major strategic issue as well as its competitiveness and security. This is outlined by several EU and national directives and by the Green Paper ''Towards a European strategy for the security of energy supply'' [1]. This is reflected in the international research context, where a key thematic area of the Sixth Framework Programme EU (FP6) and of the incoming new programme are devoted to these objectives.

The challenge that governments are trying to meet is the reduction of the increasing impacts of energy production and use (the energy sector is currently responsible for 80% of all EU greenhouse gas emissions and contribute heavily to the overall emissions of local air pollutants) guaranteeing, at the same time, the fulfilment of an increasing and more differentiated market demand. Quoting the Seventh Framework Programme FP7 [2], one of the main objectives of energy research is to reduce the dependence of imported fuels, to use a diverse mix of energy sources, in particular renewables, energy carriers and non-polluting sources, as well as to promote the creation and establishment of the technologies necessary to carry out these changes.

Governments face tough job making operating these objectives because of the intrinsic complexity of energy systems. Actions that need to be implemented involve in fact not only changes on the physical structure of the energy sector (e.g. increasing efficiency of energy production and investing in renewable sources, increasing the transport and storage capacity of infrastructures) but also on the demand side, improving consumers consciousness and bringing them to energy conservation and demand reduction.

The process of planning a structured national energy strategy can be valuably supported by comprehensive long-term modelling tools, based on a detailed (bottom-up) representation of the energy system and capable of investigate, from a technical, economic and environmental point of view, short-term solutions and long-term strategies, taking into account different standards of energy devices and technologies development as well as end-use demands evolution. These models provide answers in terms of level of activities and fuel mix, costs and emissions, suggesting a combination of actions on the demand and supply side aimed to satisfy, at the lowest cost for the energy system, the superimposed constraints related to the different policies and price mechanisms analysed. Several examples on the use of models in supporting decision-making on energy-environmental issues at local, national and supra-national level can be found in scientific literature (e.g. [3–5]).

This paper is aimed to provide further inputs in energy system analysis, bringing the main features and some operating results of an experience conducted in the integrated project NEEDS ''New Energy Externalities Development for Sustainability'', that is being carried out under the ''Sustainable Energy Systems'' thematic area of the Sixth Framework Programme. The ultimate objective of the project is to evaluate the full costs and benefits (direct and external) of energy policies and of future energy systems, both at the level of individual countries and for the enlarged EU as a whole. The case study here discussed form part of the activities of the research stream ''Modelling Pan European energy scenarios'' aimed to generate models of 29 EU countries that are subsequently integrated into a Pan-European modelling platform using a multi-region approach. This platform can hold LCA and externalities data and it is used to analyse a baseline and a set of policy scenarios aimed to assess key energy and environment issues at Pan European scale over the time horizon 2000–2050.

The following paragraphs are devoted to present the main features of the methodology adopted for this study, to describe the energy system model implemented for Italy and to discuss the main results obtained so far for the baseline scenarios at national scale.

More details on tools, assumptions and achievements can be found into to the official project documentation.

2. Methodological approach

The country models as well as the Pan-European model are being developed using the modelling platform TIMES (the MARKAL – EFOM TIMES System), made available by the Energy Technology Systems Analysis Programme (ETSAP [6]), an Implementing Agreement of the International Energy Agency (IEA), and at now used to implement national and global models worldwide.

The general modelling platform was further specialised to meet the specific objectives and technical requests of the NEEDS project, and it is actually constituted by the following components:

- the model generator (TIMES), consisting of the source code written in the GAMS (General Algebraic Modeling System)

computer programming language. It processes the data files, generates the matrix that specifies the mathematical programming problem, solves it, and post-processes the optimization results,

- a ''shell'', i.e. an user interface named the Versatile Data Analyst (VEDA), that allows creating, managing the data input and running the model generator (Front End, FE [7]), and analysing results (Back End, BE [8]),
- a set of data files that fully describes the energy system (technologies, commodities, resources and demands for energy services).

2.1. The models generator and the user interfaces

The core of the modelling framework is the TIMES economic partial equilibrium models generator. It is demand driven and technology oriented, allowing to represent all the aspects related to energy system including emissions, materials and environmental damage. Its considerable flexibility makes it a powerful tool for analysing energy systems on different spatial and time scales and for assessing the feasibility of energy-environmental policies under different constraints. It provides a technology-rich basis for estimating energy dynamics over a long-term, multi-period time horizon, allowing for a flexible division of the time horizon through an arbitrary (unlimited) number of time-periods with varying length.

The mathematical structure of TIMES is based on linear programming (LP). This means that as underlying hypothesis the objective function and constraints can be represented by linear equations.

From a mathematical point of view, the objective function (EQ_OBJ,) of the primal problem, built up with a bottom-up approach from demand categories and technological options, represents the total discounted cost of the energy system, i.e. the sum of the discounted annualised costs minus the annualised revenues of an energy system, as specified in the following equation [9]:

$$\mathrm{EQ\_OBJ} = \begin{cases} +\text{Costs for sunk material} \\ +\text{Investment costs} \\ +\text{Fixed costs} \\ +\text{Variable costs} \\ +\text{Taxes} \\ +\text{Surveillance costs} \\ +\text{Decommissioning costs} \\ -\text{Subsidies} \\ -\text{Recuperation of sunk material} \\ -\text{Salvage value} \end{cases} \tag{1}$$

All the costs that are included in the objective function are discounted to the base-year using a general discount rate specified by the user (a 4% agreed upon value was utilised for all the countries modelled in the NEEDS project). It is worthwhile to note that a technology-specific discount rate could also be considered in TIMES, feature that is important when the allowance of technologies is very different from a period to another.

TIMES computes a partial equilibrium on energy markets. This means that the model computes both the flows of energy forms and materials as well as their prices, in such a way that, at the prices computed by the model, the suppliers of energy produce exactly the amounts that the consumes are willing to buy [10].

The TIMES energy economy is made up of producers and consumers of commodities such as energy carriers, materials, energy services, and emissions. TIMES, like most equilibrium models, assumes competitive markets for all commodities. In this way, the result is a supply-demand equilibrium that maximizes the net total surplus (i.e. the sum of 'producers' and 'consumers' surpluses). Moreover it is run in a dynamic manner, that is to say that the model has a perfect foresight: all investment decisions are made in each period with full knowledge of future investments [10].

Another important feature of TIMES [11] is the multi-region approach, that allows to analyse simultaneously several energy systems (in the Pan-European model, 29 country models) linked by energy, material and emissions exchanges. This approach is very useful for analysing, for example, emission permits tradings and other issues related energy and emissions policies.

A model interface is thus necessary to allow the users to create, browse, and modify the input data, as well as and to explore and process the model's results. The VEDA interfaces (VErsatile Data Analyst), used to manage the NEEDS-TIMES model, consist of a front-end component (known as VEDA-FE), for the analysis and maintenance of the input data, and a back-end component (known as VEDA-BE) for the analysis of results through the construction of analyst tables and graphs. The front-end component must be closely matched to each specific model, whereas the back-end component applies to a variety of models.

More and detailed information on these interfaces can be found in [7,8].

2.2. The reference energy system (RES)

Each TIMES-based model is completely defined by the input provided by the users (energy vectors, materials, technology availability, commodities demand, techno-economic parameters) and characterizing the reference energy system, that schematises all the energy flows from primary sources to final uses in different sectors, through energy conversion technologies (large and small scale plants) and different distribution options (electricity grids, district heat networks).

The definition of a common RES (Fig. 1 [12]) for the NEEDS-TIMES models (country models and Pan-EU model) was the first task of the modelling set up. The ''shape'' of the RES was determined identifying, first of all, the main demand sectors (Residential, Commercial, Agriculture, Industry, Transportation, Electricity/Heat production, and Energy Supply) and the list of commodities (demand categories, energy carriers, emissions, and materials) to be modelled, as described in more details in [13].

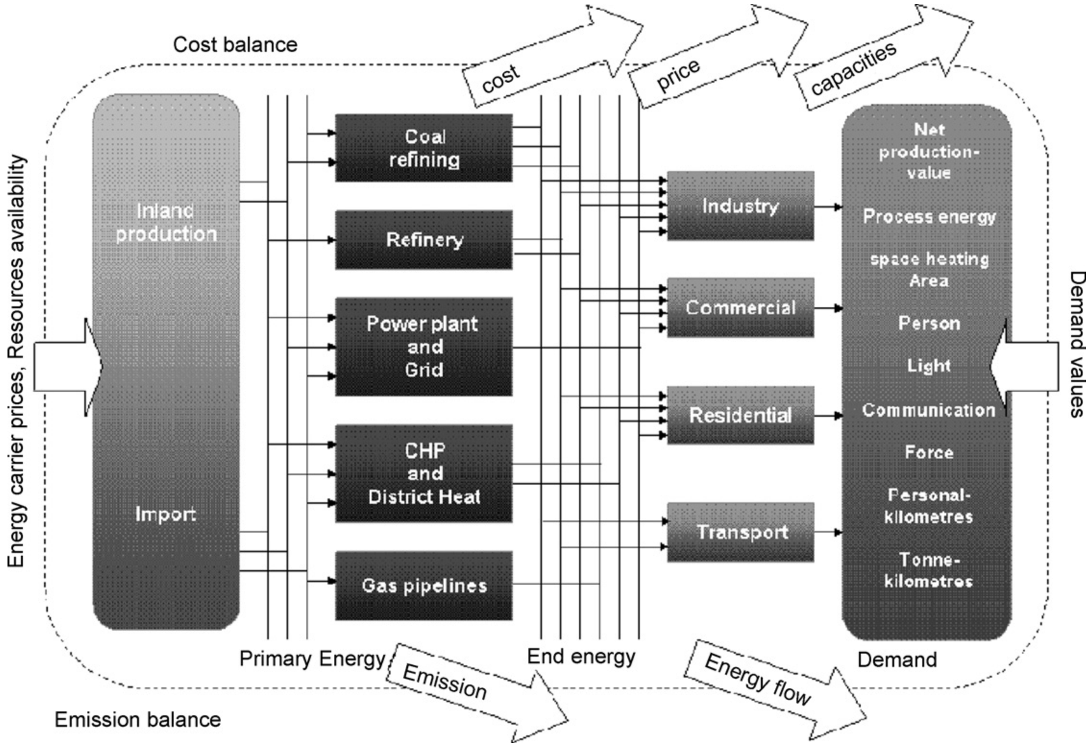

Fig. 1. A scheme of RES representation (*source*: [12]).

As concerns the *Supply*, each primary resource (crude oil, natural gas, hard coal, lignite) is modelled by a supply curve with several cost steps. There are three categories of sources: located reserves (or producing pools), reserves growth (or enhanced recovery), and new discovery. In addition, five types of biomass are modelled: wood products, biogas, municipal waste, industrial waste-sludge, and bio fuels.

Electricity and heat production regroups public power plants, auto production of electricity and CHP. In particular, three types of electricity (high voltage, medium voltage, and low voltage) and two separated (not connected) grids for long distance (high temperature) and short distance (low temperature) heat are distinguished.

The RES structure adopted for *Residential* is based on 11 main end-uses (space heating, space cooling, water heating cooking, lighting, refrigeration, cloth washing, cloth drying, dish washing, other electric, other energy), with the first three differentiated by building categories (single house: rural, urban, multi-apartment). Similarly to residential, for the *Commercial* sector nine end-uses are taken into account: space heating, space cooling, water heating, cooking, refrigeration, lighting, public lighting, other electric, other energy uses, with the first three being differentiated by building categories (small/large). *Agriculture* is modelled with a simplified approach as a single generic technology with a mix of fuels as input and an aggregated useful energy demand as output.

Industry modelling is based on a distinction between energy intensive industries, for which a detailed process-oriented RES was adopted and other industries, modelled with a standard structure consisting in a mix of five main energy uses (steam, process heat, machine drive, electrochemical, others processes). In order to promote the integration with LCA and ExternE methodologies, different material demands of the industrial sector (as for example steel or limestone) were modelled separately.

Transport includes road and rail for passengers and freight, navigation and aviation. In road transport, there are five demand categories for passenger travel (cars: short distance, long distance, buses: urban, intercity, two- and three-wheelers/off road), and trucking. In rail transport, there are three demand categories (passengers: light trains (metros), heavy trains and rail freight). The aviation and navigation sectors are modelled using a single generic technology each and a single generic demand each that reproduces the energy consumption.

Together with the RES shape, the units of measure and the main general data sources (in particular the Eurostat energy data [14]) to be used for calibration were individuated in order to guarantee a full ‘‘transparency’’ of all the models.

A common basic list of technologies (base-year technologies) was also identified, to be specialized in order to meet the specific features of each country energy system.

2.3. The data files

Once the structure of the country models was defined, the next step regarded the characterization of single energy systems by each team of experts. The main data files used to lay down the basic structure of national energy systems and to allow the calibration of energy flows at the base-year are five Excel spreadsheets per each country (the so-called ‘‘templates’’),

which have direct links to primary data sources and are periodically updated, sector by sector (RCA: residential/commercial/agriculture; IND: industry; TRA: transport; ELC: electricity/heat production; and SUP: energy supply). The main information collected were: base-year energy flows, existing technology stocks with their technical/environmental characteristics and transmission efficiency; so that consistent base-year demands for energy services are computed.

The following additional common data files were thus introduced in the next steps, and specialised per each country, to model the energy system development over the chosen time horizon:

- *Technology repository*: it contains a full list of technologies, already available or that will be available in the next time periods of the time horizon. Each technology is explicitly identified and described by a number of technical parameters (e.g. efficiency, availability, technical life of the process, construction end, dismantling lead-time, contribution to the peak equations, overall efficiency of a commodity and time-slices) and economic parameters (e.g. investment, operating and maintenance, dismantling costs, taxes, environmental costs, subsidies).
- *Demand projections*: additional parameters were introduced to describe demand curves: demand's own-price elasticity (i.e. the relationship between the quantity of demand and its price), the total allowed range of variation of demand values, and the number of steps for the discrete approximation of the curve [10]. In the NEEDS project, the construction of the reference useful energy demand projections was based on the general equilibrium model GEM-E3 (EU22 countries) [15], that allows generating a consistent set of drivers to be used in the TIMES models (GDP and GDP per head growth, private consumption as a proxy for disposal income, sectoral production growth). A special GAMS program was written to compute the projections based on GEM-E3 results, specific assumptions and base-year calibration data [16].
- *User constraints*: provide information on the various exogenous system's boundaries according to the scenario hypotheses. In the NEEDS context, a baseline (*BAU—Business As Usual*) scenario as well as policy scenarios are analysed. The user constraints are useful not only to reproduce the standard boundary conditions but also to analyse the effects of policies on the energy system (e.g. limits to pollutant emissions, resources availability, RES potential, etc.) that can be modelled in terms of bounds on the overall or net production of a commodity, on imports and exports of commodities, on emissions.

3. The Italy NEEDS-TIMES model

According to the latest census conducted in 2001 by ISTAT, Italy has a population of 56.3 million, with a GDP of 1191.057 bill of current Euro2000. The country is divided into 20 administrative Regions – 5 of which have special autonomous status that enables them to enact legislation on some of their specific local matters – 103 Provinces and 8101 Municipalities.

Italy is a highly developed country with the sixth largest economy in the world in 2004, its economic strength being in the processing and manufacturing of goods, primarily in small and medium-sized family-owned firms.

The complexity and variability of the Italy energy system required a careful modelling activity, in order to take into account its main features and to overcome the problems related to a general lack of updated data necessary to characterise the templates.

In the next paragraphs, the Italian energy system is described from the supply to the demand sectors, resuming the main features and specific assumptions with reference to the sub-sectors. Regarding air emissions, only carbon dioxide was considered in this study in order to take into account the contribution of each country to the overall amount at the Pan-European level.

3.1. Supply

Italy is characterized by few natural resources and by a massive use of gas (more then any other European country) due to the rejection of nuclear power and to a greatly reduced use of coal to generate electrical energy.

Energy dependence and fossil fuels supply security are now and will continue to be over the coming years a major criticality in the country economic development: it has been estimated that 91.8% of all the raw materials required to satisfy the national energy needs were imported in 2005 (compared to the 64.7% of EU) and that this figure will increase to 98.8% by 2025 (EU value: 82.7%) under the current trends [17]. Another problem related to supply is the inadequate infrastructure system, especially with regard to the gas transport and storage system, that has not kept pace with the evolving demand.

In the following, the main assumptions adopted to model the Italian energy supply are described, with reference to fossil fuels (reserves and domestic extraction, imports and exports), electricity, heat and renewable fuels.

3.1.1. Fossil fuels

As concerns reserves and domestic extraction, of major importance is the crude oil production, on which Italy has a long history. According to WEC [18], the proved recoverable reserves of crude oil at end-1999 were 61 Mtonnes (448 Mbarrels) whereas the estimated additional reserves recoverable were 28 Mtonnes (203 Mbarrels). The correspondent production was of 5 Mtonnes (100 Mbarrels), with a R/P (reserves/production) ratio of 0.05. Total oil output (including minor quantities of NGLs) has been falling in recent years. The refinery capacity in 2000 was of 2294 thousand barrels daily and it is remained constant till 2004 [19]. The Italian Oil production is only a small portion of the total requirement (5% in 2001, according to WEC [18]), so most part of the supplies comes from abroad (mainly Russia and Libya), both as crude input to national refineries and as refined products.

As concerns natural gas, the proved recoverable reserves at end-1999 were 191 billion cubic metres, the estimated additional reserves recoverable were 44 billion cubic metres,

the production was 17.5 billion cubic metres, with a R/P ratio of 10.9. It is mainly imported by pipeline from Algeria and Russian Federation (respectively 38.4% and 34.2% in 2004 according to BP [19] whereas only a very small export (0.06 billion cubic metres) was noticed in 2004 towards Croatia. In 2004, the same data source reports for LNG (liquefied natural gas) a total import of 5.9 billion cubic metres, of which 64.4% from Nigeria and the remaining part from Algeria.

Coal importance in the country's energy needs has declined (only 6.8% in 2002, one of the lowest levels in the EU), and it is mainly used to fuel electricity generation. Italy was one of the first European countries to completely stop domestic production, with the last facility closing in 2001 [20]. It is mainly imported from Indonesia and South Africa, followed by Colombia, Australia and Ukraine whereas only a small percentage (1.2% in 2005) comes from Europe (mostly from Poland).

Coke is imported from China, Bosnia-Herzegovina, Japan and Ukraine and it is mainly (82.7% in 2005) exported into EU, in particular France and Germany.

Moreover, for Lignite, the proved amount in place at end-1999 was 15 million tonnes, whereas the estimated additional amount in place and reserves recoverable were respectively 22 and 20 million tonnes. It is totally imported from Germany.

With reference to the modeling aspects, only small corrections were done in the Eurostat energy balance for these fuels, with the aim to assure consistency to the overall balance of this sector (production and consumption, taking into account losses, storages, imports/exports) and for each fuel.

3.1.2. Electricity and heat

Italy is a major power producer. According to GRTN [21] at the end of 1999 Italy counted on a net capacity of power plants of 73.9 GW (12.9% of the EU capacity and 2.2% of the World capacity), and on a total gross electricity production of 265.7 TWh (10.5% of EU15 and 1.8% of the World), with a net production of 243.8 TWh (EU15: 2369 TWh).

Although Italy produces nearly three quarters of its power from fossil fuels (being in 1999 the gross electricity production 209.1 TWh, on a total of 265.7 TWh), the Italian power industry was a pioneer in exploiting renewable energy sources in electricity generation [18]. With its 52.2 TWh Italy is, in fact, the third largest hydroelectricity producer in EU15, after France (77.1 TWh) and Sweden (70.3 TWh). Moreover it is the fourth world producer of power from geothermic sources (4.4 TWh) and it ranks sixth in the world for wind and solar power. In general, thermoelectric power provides the base-load production whereas peak-load demand is satisfied by hydroelectric and turbo-gas power.

As concerns power generation from fossil fuels, oil has been for many years the principal energy source but in last years thanks both to an increasing concern for the environmental issues and to the diffusion of CCGT technologies, natural gas has surpasses oil, representing nowadays the first energy source for power generation in Italy [18]. This is particularly true for CHP plants (that represent 58% of the total gross production), where natural gas provides 44% of the CHP production, followed by oil (39%) and coal (12%). For conventional power plants it can be noticed an opposite situation: natural gas provides 36% of the production versus the 46% of oil (39%), whereas coal gives 16%.

Autoproducers contribute to 7.6% of the total gross electricity production (compared to 92.4% of public producers), with a larger contribution in the thermoelectric sector (8.6%) and only 3.5% in the hydroelectric sector.

Italy is also a net importer of electricity from neighbor countries, importing 48.4 TWh of energy and with an import/export balance of 42.0 TWh (EU15: 24 TWh). The transmission network is based on 9782 km of total grid at 380 kV, 11,980 km at 220 kV and on 44,046 km of total grid at 150–132 kV.

As concerns the demand sector, the power use is higher for Industry (53%, 148192.4 GWh), followed by Commercial (23%, 65108.8 GWh), Residential (22%, 61111.7 GWh) and Agriculture (2%, 4906.6 GWh). The per capita electricity use is 4959 kWh/inhabitant (EU15: 6373 kWh/inhabitant) with a density of 972 MWh/sq. km (EU15: 764 MWh/sq. km).

These values almost agree with those reported by Eurostat (except for slight differences) some modifications were necessary in the related template's data. On the other hand, in the base-year energy balance from Eurostat (PJ) there were some evident inconsistencies and lack of data, that required further computations, corrections and integrations in both the ELC template and the IND one (where autoproducers of electricity and heat are explicitly modeled).

3.1.3. Renewable fuels

The total primary energy supply of renewables in 2000, as reported by Eurostat, is 358 PJ (8.5 Mtonnes). This values agrees with that reported in the official national energy balance [22] and also with a study conducted by IEA [23], which outlines an increase of primary production of renewables in Italy from 6.5 Mtonnes (272 PJ) in 1990 to 9.7 Mtonnes (406 PJ) in 2001.

This growth over the past decade was largely due to the rapid increase in the use of solid biomass, MSW and biogas. Hydropower accounts for the largest share of renewables (44.6% in 2000), but geothermal (36.3%) and biomass (wood and wood waste: 13.0%) are also significant contributors. Solar and wind energy still contribute very little to renewable energy supply.

3.2. Demand

The final energy consumption, with reference to the analysed demand sectors, shows that the main contributions are given by transport (35%), industry (32%) and residential (21%), followed by commercial (9%) and agriculture (3%). This outlines the importance of analysing in detail the demand side in order to find out suited interventions aimed to a reduction of fossil fuels consumption, an improvement of environmental performances of end-use technologies and a reduction of atmospheric emissions from these sectors.

3.2.1. Residential, commercial and agriculture

In 2000, the total consumption of the residential sector was 1145 PJ, of which natural gas and electricity contributed respectively for 61.5% and 19.2%, followed by 13.2% of petroleum products (mainly diesel oil). Only 5.1% comes from renewable energy sources. In terms of end-use demands, the residential energy demand is mainly due to space heating (54%), followed by water heating (24%), cooking (11%) and electrical uses (11%) and cooling (0.02%).

In the base-year energy balance from Eurostat (PJ) it was evident the lack of data regarding heat consumption, whereas the Italian District Heating Association [24] pointed out that this sector utilises 60% of the total heat provided in the grid, giving a value of nearly 9.4 PJ. Moreover, comparing the Eurostat values with those reported by the official National Energy Balance [22]; there were found unacceptable inconsistencies due by a massive underestimate (1.84 PJ instead of 220 PJ) of Natural gas for Residential and a wrong sharing of other fossil fuels consumption between Residential and Commercial, as summarised in the graph of Fig. 2.

Assumptions were introduced to characterise the number and typology of dwellings (21,653,288 occupied households out of 27,291,993 total, according to ISTAT [25]), to project useful energy demand and to define stocks, efficiencies and market shares of several technologies (e.g. boilers, heat pumps, air conditioning systems, light bulbs, stoves, refrigerators, cloth washers, cloth dryers, dish washers), as described extensively in [26].

The Commercial sector takes into account the consumption of public services (public administration, schools, hospitals, etc.) and private ones (commerce, restaurants, insurances, etc.). In the last recent years the contribution of Commercial to the total energy demand of the Civil sector has increased from 29% in 1995 to 33% in 2003 [27]. In 2000, its consumption was of 502 PJ (30% of the total demand) and the main used energy source were natural gas (46.8%) and electricity (40.6%) (Fig. 3). The final energy consumption per end-use, comprehensive of 5.6 PJ of heat added to the Eurostat energy balance figures (according to AIRU [24] this sector absorbs 36% of the total heat provided to the grid) is: space heating (40%), space cooling (0.02%), water heating (25%), cooking (12%), electrical uses (23%).

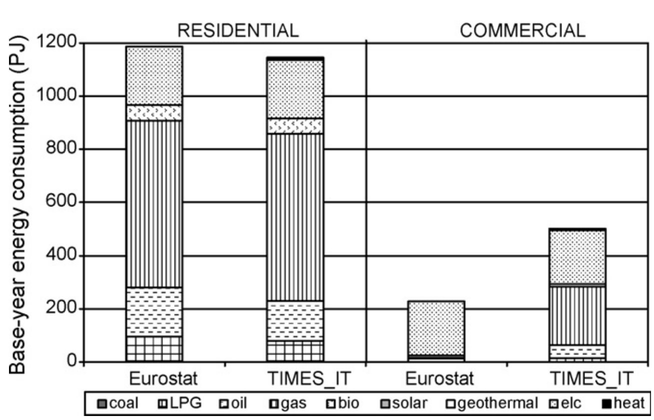

Fig. 2. Summary of the changes done in the residential and commercial energy balance.

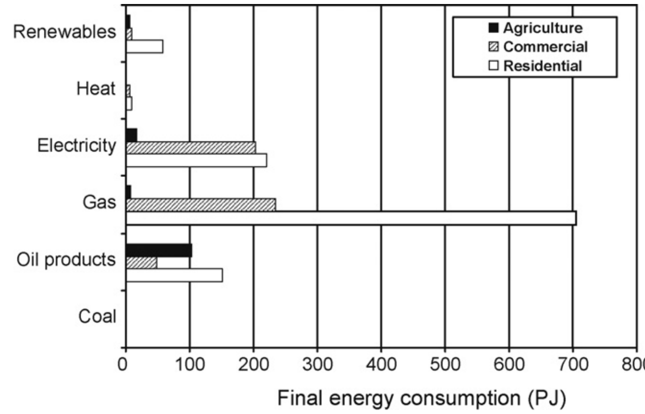

Fig. 3. Final energy consumption of residential, commercial and agriculture by energy source in 2000 (*source*: CNR-IMAA elaboration on Eurostat data).

Apart from the inconsistencies found in the Eurostat balance, it should be pointed out that this sector is characterised by a general lack of specific data thus to cope with the detail level required by the sector template, several assumption were necessary to characterise its template.

According to the preliminary decisions, Agriculture was modelled in a simplified way, that is as a ‘‘black box’’ comprehensive of energy inputs and emission outputs. This choice will not prevent possible future exploitation of this sector, also by the light of the increasing role of biofuel cultivations and possible energy saving interventions. The Eurostat base-year energy balance of this sector was very similar to that reported in official national statistics (among which ENEA [27]), reporting 134 PJ of total consumption in 2000, with a predominant contribution of petroleum products (76.6%, mainly gas/diesel oil), followed by electricity (13.2%), gas (6.1%), and renewables (4.2%, biomass), as reported in Fig. 3.

3.2.2. Industry

This sector's template takes into account also industrial electric and thermal autoproducers, whose computation required complex calculations and integrations to overcome inconsistencies and lack of data, above all, in the explicit characterisation of CHP autoproducers (more detailed information can be found in [26]). In brief, the main problem encountered in the characterisation of this template dealt with the setting up of the Eurostat Italian energy balance, where it is represented only the heat sold to third parties by industrial autoproducers, not explicating that produced and consumed in the same sector. Moreover, the reported input fuels to autoproducer thermal power station take into account also a hidden share related to heat production that had to be computed separately according to the values provided by the national association of autoproducers [28].

In 2000, Industry had a net (autoproduction excluded) total consumption of 1715 PJ (2198 PJ, taking into account also the input fuels for autoproduction of electricity and heat). The

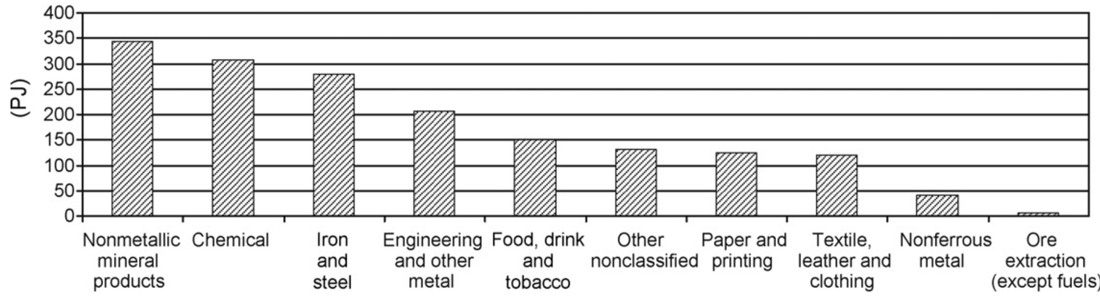

Fig. 4. Final energy consumption of industry by sector in 2000 (*source*: CNR-IMAA elaboration on Eurostat data).

industrial activity has then presented a contraction in the following years 2001–2003, mainly due to the increasing competitive pressure [27]. As reported in Fig. 4, two-thirds of the final energy consumption of the sector is due to industries producing non-metallic mineral products (20.1%), chemical (17.9%), iron and steel (16.3%), and engineering and other metal (12.1%).

With regard to the final energy consumption by energy source, it can be noticed (Fig. 5) that gases (mainly natural gas) are the most used (33.9%), closely followed by electricity (29.8%). Also important are petroleum products (15.1%), heat (12.2%) and coal (8.3%).

The characterisation of industrial sub-sectors required many efforts. The share of fuel consumption by sub-sectors was obtained referring to data provided by the national industrial associations, where possible, and to the natural gas and electricity consumptions reported by the Gas Intensive Association. The characterization of technologies was based on the results of the ECN-MATTER project [29,30]. These data were then adjusted, where necessary, to the national situation until a perfect match between the Eurostat energy balance data and those calculated on the basis of the hypotheses above mentioned was reached. Table 1 summarises the industrial sub-sectors demands (evaluated from the data provided by sector-industrial associations), the reference data sources and some assumptions used for characterising energy intensive industries.

3.2.3. Transport

As concerns this sector, detailed information on transportation modes are available per several EU countries by DG TREN and were integrated with the Eurostat data. In transport,

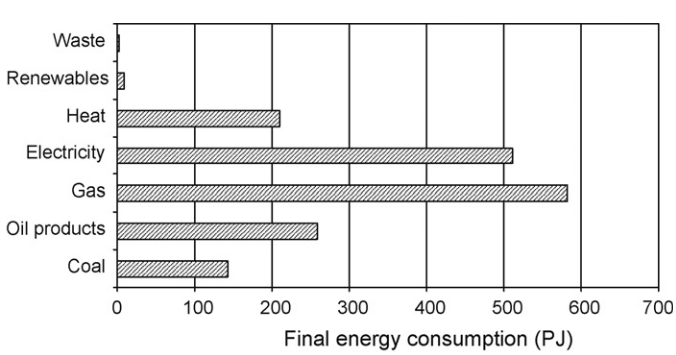

Fig. 5. Final energy consumption of industry by energy source in 2000 (*source*: CNR-IMAA elaboration on Eurostat data).

petroleum products account for 94.1% of the total consumption, followed by gas (4.3%) and electricity (1.6%). In particular, the main contribution to the overall energy consumption (1841 PJ) is given by road transport (83.5%), whereas air, inland navigation and rail transport accounts respectively for 8%, 6.6%, 1.9%.

The base-year energy balance from Eurostat (PJ) was comparable with the national official one [27]. Only two main changes were done to harmonise the basic data to the template requirements. To take into account the actual natural gas consumption (about 13.7 PJ) without modifying drastically the templates structure, it was introduced a specific technology for Road transport to LPG consumption, increasing its value from 65.4 to 79.1 PJ. Taking into account this assumption, the breakdown of consumption by fuel and by sub sector is shown in Table 2.

At the same time, the stock of two- and three-wheelers estimated by DG TREN (3376 thousand of vehicles) was increased to 7827 thousand, according to the latest data made available by the Italian Ministry of Infrastructures and Transport [31], which include also a recent estimate of mopeds, neglected so far. The final values of the vehicles stock are reported in Table 3.

3.3. Carbon dioxide emissions

The national agency for the protection of the environment [32] in 2000 estimated a total emission of carbon dioxide of 445 Mtonnes, of which 98% are due to the energy sector, 5% to industrial processes whereas changes in land and forest use give a credit of 4%.

In the TIMES_IT model, carbon dioxide emissions were mainly computed with reference to fuels combustion, using the emission factors reported in Table 4. These factors are contained in the EMI sheet of templates and are considered constant from 2000 till the end of the time horizon. An additional estimate of CO_2 from processes was taken into account for energy intensive industrial sectors (aluminium, cement, lime, glass, iron and steel).

4. Main national energy and environmental policies

In order to characterise the energy system behaviour on the time horizon a careful analysis of the national normative

Table 1
Summary of the main demands and data sources for the Italian industrial sector

Industry sub-sectors	Code	Demand (source)	Unit	Main assumptions
Iron and steel	IIS	26.62	Mtonnes	Raw iron produced by Blast Furnace. Crude steel by electric arc furnace (62%) and by blast oxygen furnace (38%), a 21% of it utilizes scraps
Aluminium	IAL	0.93	Mtonnes	40% of aluminium produced by recycling aluminium scraps, and the remaining 60% by Hall-Heroult process
Copper	ICU	1.34	Mtonnes	56% of copper produced by recycling of scraps, the remaining from new materials
Other non-ferrous metals	INF	3.72	PJ	
Ammonia	IAM	9.4	Mtonnes	50% of ammonia by standard production and 50% by advanced processes
Chlorine	ICL	0.6	Mtonnes	Chlorine produced for 22% by standard and 78% by advanced membrane
Other chemicals	ICH	161.77	PJ	
Cement	ICM	39.80	Mtonnes	98% of the total clinker production through dry process. Proportions given for clinker kilns, by input fuel
Lime	ILM	4.20	Mtonnes	
Glass hollow	IGH	3.70	Mtonnes	34% of the production carried out using recycled glass
Glass flat	IGF	0.84	Mtonnes	
Other non-metallic minerals	INM	77.68	PJ	
High-quality paper	IPP	2.99	Mtonnes	Pulp paper production: 59% by mechanical process, 13% by chemical process and 28% by pulp recycling. The pulp produced is used to obtain low and high quality paper
Low-quality paper	IPP	6.01	Mtonnes	
Other industries	IOI	520.05	PJ	
Non-energy consumption—chemicals	NEC	320.7	PJ	
Non-energy consumption—others	NEO	141.7	PJ	

orientation on energy and environmental themes was carried out. The main outcomes are reported in the following.

- *Liberalisation of energy markets*, in particular it deals with the distribution in the oil sector (effective by 1 July 2000, according to law 29 December 1999, n. 496); the electricity market with the realization from 2003 of an Italian Exchange of electricity (The Legislative Decree 16 March 1999 n. 79); and the gas sector (Decree 164/00), for which establishes a degree of market opening greater than that required in the European Natural Gas Directive 98/30/CE.
- *GHG emissions reduction and implementation of the Kyoto targets*: The Italian Parliament ratified the Kyoto Protocol in 2002 (Law n. 120/2002) and was engaged to reduce the national GHG emissions by 6.5% compared with the 1990 reference values within 2012. The policy measures undertaken to achieve the prefixed targets were designed in the ‘‘National Action Plan for the reduction of GHG emissions’’ (CIPE Decision of 19 December 2002) and other specific measures and tools were carried out at national level to obtain a reduction of GHG emissions. The main ones include a progressive carbon tax (Law n. 448/98), not yet made fully operating; the carrying out of the IPPC (Integrated Pollution Prevention and Control) Directive (Legislative Decree 4 August 1999 n. 372) for maximizing energy efficiency in industry, tertiary and residential and to reduce the thermal losses in new and existing buildings; a voluntary agreement between ministries and the leading Italian power company on the substitution of existing thermoelectric systems with low efficiency; and actions to foster the diffusion of vehicles with a reduced environmental impact as well as to develop efficient strategies for supporting public transport (Ministry Decree of 18 October 2002).
- *Renewable energy sources*: Following the White Book of the European Union, that establishes as a minimal objective to doubling the energy contribution from renewable sources (on the whole EU15 countries) within 2010, the Italian Parliament has promulgated a decision (White book for valorisation of renewable energy sources, approved from CIPE on 6 August 1999) in order to increase electric energy production from renewable sources (from 10.7 Mtonnes of 1997 to 16.7 Mtonnes within 2010). With this orientation, several normative have been introduced, for instance, to introduce into the national system a 2% minimum share of

Table 2
Base-year data aggregated by sector fuel for the Italian transport sector (PJ)

PJ	LPG	Motor spirit	Kerosene—jet fuels	Diesel oil	Heavy fuel oil	Natural gas	Biodiesel	Electricity	Total
Rail	0	0	0	6	0	0	0	29	35
Road	79	734	0	725	0	0	0	0	1538
Air	0	0	146	0	0	0	0	0	146
Inland navigation + bunkers	0	0	0	44	78	0	0	0	122
Total	79	734	146	774	78	0	0	29	1841

Table 3
Base-year Stock of vehicles running in Italy (thousand)

	Cars (thousand)	Motos (thousand)	Buses (thousand)	Freights (thousand)
Diesel	4,798		86	2986
Gasoline	26,195	7827	1	362
LPG	1,292			
Total	32,285	7827	87	3348

electricity produced from renewable sources (Legislative Decree 16 March 1999 n. 79); to introduce the Green Certificate fostering power generation from renewables through a preferential price (Ministerial Decree 11 November 1999); to improve energy performance of buildings as well as to foster the integration of renewable energy sources and energy diversification (Legislative Decree 19 August 2005 n. 192). Moreover laws were promulgated to guarantee an annual increase of 0.35% of the minimum share of electricity from renewables (Legislative Decree 29 December 2003 n. 387), to reach within 2015 the installation of a photovoltaic nominal cumulated power of 1000 MW (Ministry Decree 6 February 2006), to improve biodiesel and bioethanol production (National Program for the Valorisation of Agricultural and Forest Biomasses - CIPE deliberation n. 217/1999) and to promote the use of biofuels and others renewable fuels in Transport (Legislative Decree 30 May 2005 n. 128).

- *Energy saving*: The most important national normative references establish the reduction of primary energy consumption that must be achieved by natural gas distribution enterprises (Ministry Decree 24 April 2001), and set national overall objectives of energy saving quantitative targets for increasing energy efficiency of end-users (Ministry Decree 20 July 2004).
- *Local air pollutant*: Limits and policy measures for their reduction are established by several national laws (e.g. the Legislative Decree 21 May 2004 n. 171 identifies the following national emissions ceilings: 475 ktonnes for SO_2, 990 ktonnes for NO_x, 1159 ktonnes for VOC, and 419 ktonnes for NH_3 to be achieved by the year 2010).

Table 4
Carbon dioxide emission factors, from combustion

Fuel	Code	kt/PJ
Hard coal	COAHAR	98.3
Coke	COACOK	94.6
Total lignite	COALIG	101.2
Brown coal briquettes	COABRO	101.2
Light petroleum gas	OILLPG	63.1
Gasoline	OILGSL	69.3
Kerosene	OILKER	71.9
Diesel	OILDST	74.1
	OILHFO	77.4
Heavy fuel oil	OILOTH	73.3
Crude oil	OILCRD	73.3
Non-energy use	OILNEU	0
Naphtha	OILNAP	73.3
Refinery gas	OILRFG	56.1
Feedstock (for refinery)	OILFDS	73.30
Natural gas	GASNAT	56.1
Gasworks gas	GASGWG	56.1
Coke oven gas	GASCOG	108.2
Blast furnace gas	GASBFG	108.2
Wood and wood products	BIOWOO	0
Biogas	BIOGAS	0
Municipal solid waste	BIOMUN	85.85
Sludge	BIOSLU	85.85
Biofuels	BIOLIQ	0

5. BAU scenario assumptions

In compliance with the decisions taken for the Pan-European model scenarios, also for the Italy NEEDS-TIMES model the baseline (BAU) scenario is characterised by exogenous assumptions around drivers, energy prices and policies that follow a rather business as usual trend as derived with the help of the general equilibrium model GEM-E3. The macroeconomic and energy price background assumptions are in line with those reported in the latest DG TREN projections. The reference scenario is without a specific climate policy (no constraints on the reduction target of carbon dioxide) such as to allow a proper evaluation of Kyoto and post-Kyoto targets. This follows a common choice taken inside the research stream, that is to avoid a double constraint on this emission in the Pan European framework. Nevertheless the effects of applying a CO_2 constraint will be analysed in further runs of the Italy model.

Besides these common assumptions there were introduced those inherent the regulations in force and the current energy-environmental policies. In particular with reference to the demand side, the sector by sector assumptions are:

- *Residential*: the 2001 and 2005 balances were constrained to assure that the Eurostat national balance values were reproduced in the results; some additional parameters were utilised to characterise the GEM-E3 forecasts of the Italian Residential demand (as described in [26]); and it was imposed an increase of solar thermal use according to the White paper targets that foresee 3 million of m^2 of solar collectors installed till to 2010.
- *Transport*: the fossil fuels consumption was estimated taking into account the Italian Oil Union forecasts [33] till to 2020 and extrapolating these values on the whole time horizon; the percentages of biofuels used for the period 2005–2010 were estimated according to the Legislative Decree 128/2005 as follows: 1.0% (end of 2005); 2.5% (end of 2010) and a constant increase was considered from 2015 in order to achieve a maximum percentage of 8% in 2050.

On the supply side, the main hypotheses introduced are:

- Nuclear plants were not considered, according to the results of the abrogative referendum held in 1987.
- Imports and exports of electricity were set equal to the 2005 values on the whole time horizon.
- Coal and oil consumption for electricity production was determined according to the Italian Association of Oil Companies forecasts [33] till to 2020, extrapolating these values up to 2050.
- No new large hydropower plant was provided over the considered time horizon.
- The annual share of electricity generated by renewable energy sources (wind, mini-hydroelectric, geothermal, waste, biogas and wood) was defined taking into account the annual growth of last decade (3.29% over the 1995–2004 period) [27]. In addition to that, the maximum potential of each source has been limited according to the ‘‘White Book’’ estimates [34].
- A nominal cumulated power of 1000 MW for photovoltaic was provided within 2015, according to the objectives of the Ministerial Decree D.M. 6/2/2006.
- Imports and export of some fossil fuels (naphtha, hard coal, coke) were set equal to the official values till to 2005 and then increased stepwise up to the maximum achieved in 2050.
- The potential for the domestic production of energy crops and rape seed was defined according to the national potentials [35].

6. Main results

Runs of the BAU scenario were carried out in order to assess the energy system behaviour over the time horizon and to obtain a reference baseline for scenario analysis.

A preliminary step of results analysis was devoted to ‘‘calibrate’’ the model, so as to validate the initial set of data (based on official energy balances), assumptions and modelling choices. The next step involved an evaluation of the consistency of the model response in terms of energy, materials and emission balances as well as capacities and operating levels of all the analysed technologies.

In this very careful iterative process, significant inconsistencies (data missing or unacceptable values) were found in the Eurostat database and were opportunely eliminated having recourse to data and specific studies coming from other national sources.

The main results obtained for the BAU scenario are reported in the following.

6.1. Primary energy

The primary energy consumption, after an initial decrease (8%, 2005 data), grows constantly on the entire time horizon, as shown in Fig. 6. In the base-year oil is the most used fuel (3329 PJ), decreasing up to 2907 PJ on the whole time horizon due to less consumption in electricity production. Nevertheless it remains the predominant fuel in the transport sector (RPPs).

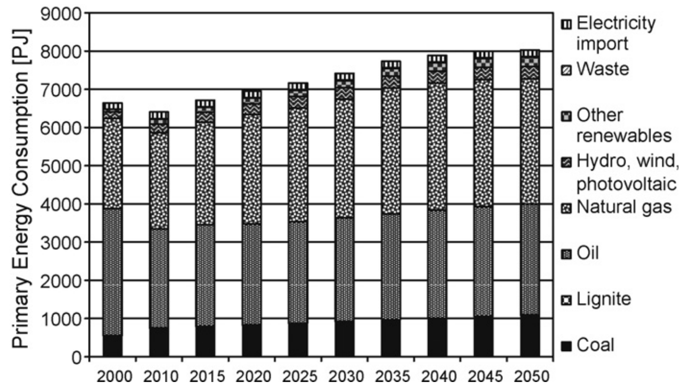

Fig. 6. Primary energy consumption and net electricity import.

On the contrary, natural gas consumption increases both in electricity production and Industry. Also coal consumption increases (75%), mainly in the electricity production and in the Industry sector.

Regarding the renewable energy sources, a gradual growth of photovoltaic and wind use for electricity production on the whole time horizon can be noted according to the regulations in force. Moreover it could be observed an increase use of solar thermal for residential water heating and commercial space heating.

6.2. Electricity and heat generation

On the overall time horizon the electricity production increases from 250 TWh in 2000 to 352.7 TWh in 2050 (about 41%), with a installed capacity in 2050 of 73 GW. This production is characterised by an increasing contribution of CHPs (from 12% in the base-year to 39% in 2050).

As shown in Fig. 7, the most used fuels are natural gas, coal and hydro, whose contribution in 2050 is respectively 52%, 19% and 18%. According to the oil companies forecasts [33] there is a reduction of oil products use for electricity and heat generation whereas there is an increase of coal use, fostered by the diffusion of new technologies characterized by more efficient abatement devices for air pollution control and flue gas treatment.

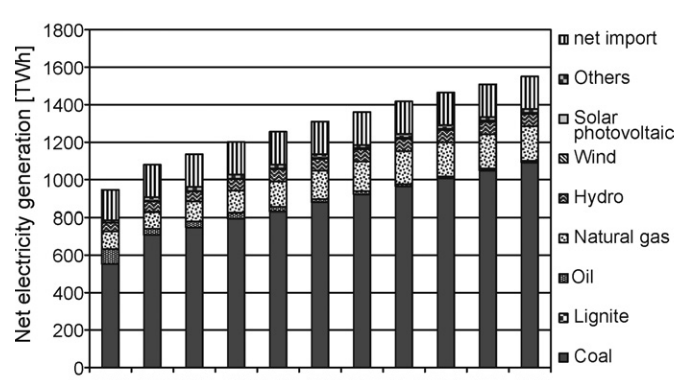

Fig. 7. Net electricity generation by fuel.

Hydropower contribution to the net generated electricity achieves 25% due to the installation of new mini hydro plants from 2001.

Wood, geothermal, waste, and biogas contribution to the net generated electricity (accounted as ‘‘Others’’ in Fig. 7) in 2050 is about 7.57 TWh, 6.4 TWh, 3 TWh and 1.81 TWh, respectively.

Electricity production by industrial autoproducers is also increased (from the initial 37.1 TWh to 126.3 TWh in 2050) with an increasing contribution of CHPs (from 16 TWh in year 2000 to 126.3 TWh final, corresponding to a net capacity of 17.2 GW). Natural gas is the most used fuel, whereas oil and coal are cut off respectively in 2040 and 2045.

Industrial autoproducers contribute also to the fulfilment of an increasing heat demand (from 226.7 PJ in the base-year to 562.2 PJ in 2050, mainly due to industry and commercial), increasing their production from 210 PJ in year 2000 up to 520.8 PJ in 2050, whereas heating plants contribution (both public and industrial) is about 3% and reduces itself until zero from 2030.

Also public CHP energy consumption for heat and electricity production increases 2.5 times on the whole time horizon, being characterised by a prevalent use of natural gas (80% in 2050), whereas wood, waste and other gases (biogas, derived gases, coke oven gas and blast furnace gas) contribution is respectively 12%, 8% and 0.4%, accounting for the remaining 20%.

As a consequence, fuels consumption in industrial CHP plants increases remarkably (70% in 2050), with a prevailing use of natural gas (the only used fuel from 2040 onwards).

6.3. Final energy demand

Following the increase of energy demand, there is an increase of fuel consumption by all sectors (Fig. 8) on the time horizon. In particular, heat, coal and renewables have the most remarkable increase (respectively, heat from 225 PJ of the base-year to 562 PJ in 2050, coal from 195 to 485 PJ and renewables from 81 to 175 PJ).

Natural gas, electricity, waste and oil products increase is respectively 47%, 39%, 13% and 7%.

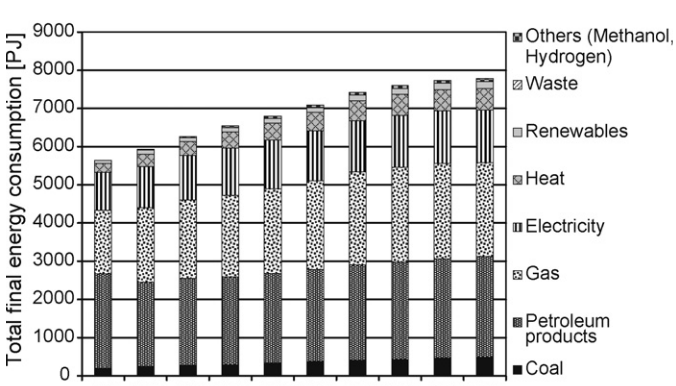

Fig. 8. Total final fuel consumption by fuel.

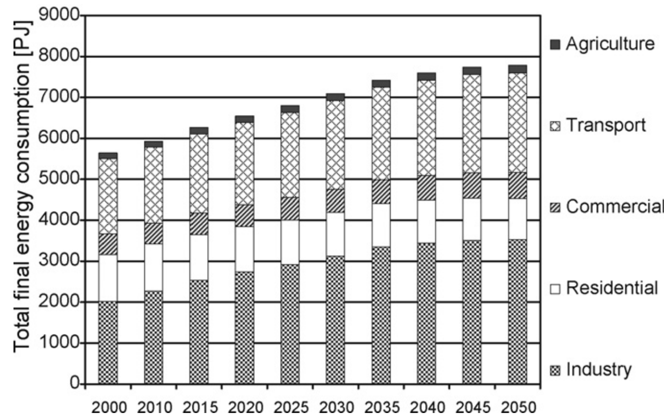

Fig. 9. Total final fuel consumption by sector.

Methanol and hydrogen (others), are being used from 2010 in the transport sector, their contribution increasing from 19 PJ up to 82 PJ in 2050.

As concerns the sector by sector energy consumption (Fig. 9), the results are summarised as follows:

- *Industry*: there is a 74% overall increase in 2050 respect to the base-year value, with a net reduction of petroleum products use (−41%), and a remarkable increase of coal (152%), heat (150%), natural gas (98%), electricity (37%), renewables (26%) and waste (13%). Among coal products, lignite, that until 2030 is used from Iron and Steel industry, after 2035 is used for clinker production. Another switch regards natural gas that at the base-year is mainly used from Other Non-Energy Intensive industries (ONE), and in 2050 mainly from Chemical Industries for ammonia production.
- *Commercial*: the energy consumption increases 27%. As concern fuel use, there is a consistent reduction of oil products and natural gas use (respectively −81% and −16%) on the whole time horizon, whereas heat, renewables and electricity increase respectively from 5.7 to 35 PJ, from 8.9 to 22.5 PJ and from 203 to 361 PJ in 2050. Nevertheless natural gas is still the prevailing fuel for the fulfilment of space heating demand with an increasing consumption (157 PJ in 2050). Electricity is mostly used for water heating (109.7 PJ in 2050). The base-year energy demand for cooking is fulfilled 59% by electricity, 34% natural gas and 7% by other fuels, whereas in 2050, electricity share being constant, natural gas share increases up to 40%.
- *Residential*: according to a decreasing demand trend fostered by more efficient technologies and new building standards, energy consumption decreases 12% on the overall time horizon. As concerns fuels breakdown, coal is cut off from 2030, whereas electricity and natural gas consumption increases respectively 6% and 3%. Also heat, petroleum products and renewables consumption decreases (respectively 91%, 55% and 51% in 2050). However, renewables use decrease is mainly due to a smaller use of wood, whereas at the same time solar thermal increases from 0.46 to 9.63 PJ in 2050.
- *Agriculture*: in agreement with an overall estimated 28% of energy demand growth, fuel consumption shows a quite

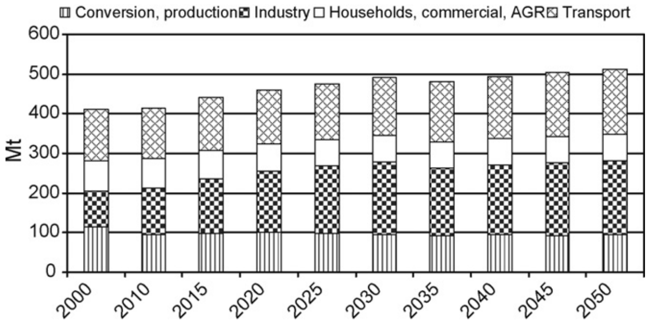

Fig. 10. Carbon dioxide emissions.

linear increase. As this sector is modelled as a single generic technology, the fuel share is obviously unchanged; oil products and electricity being the most used fuels (respectively 76% and 13%).

- *Transport*; total fuels consumption increases 32% on the whole time horizon. In 2050, the refined petroleum products share is 91%, renewable (methanol, hydrogen DME, ethanol and biodiesel) accounts for 7%, and electricity for the remaining 2%. Methanol and DME consumption are in line with the national policies. As concerns road transport, cars show higher consumption of gasoline (630 PJ) rather than diesel (176 PJ) in the first time period; on the contrary, diesel consumption increases up to 341 PJ whereas gasoline consumption decreases up to 257 PJ in 2050. Liquefied petroleum gas–LPG consumption decreases from 79 to 63 PJ on the whole time horizon. As concerns buses, diesel consumption is prevailing on the whole time horizon and there is a small consumption of gasoline until 2010. Freight transport demand is almost completely fulfilled by diesel that goes form 87% of the base-year up to 92% in 2050, the remaining 8% accounted by biodiesel. Until 2005 a little amount of gasoline is used (6%) that is cut off after 2010. As concerns rail transport, the most used fuel is electricity whose consumption increases from 29 PJ in the base-year to 39 PJ in 2050. The sharing out between passenger and freight transport is about 2:1 (the consumption for passenger and freight transport is respectively 19.5 PJ and 10 PJ in 2050).

6.4. Carbon dioxide emissions

No Kyoto policies are considered in the baseline scenario therefore, following the consumption trend, carbon dioxide emissions increase 24% in 2050; the highest contribution is given by industrial sector that doubles its emissions between 2000 and 2050 (Fig. 10). Also in transport sector there is a remarkable increase of emissions (+26%) due to the increase of oil products use. On the contrary, in the conversion sector there is a 14% reduction, due to an increased use of renewables (hydro, wind, and photovoltaic) for electricity production.

7. Conclusions

This paper is mainly aimed to present the methodology approach and the first results achieved in an experience of energy system modelling, trying to outline the effectiveness of this approach in energy analysis and decision-making. The presented results can be interpreted as a possible evolution pathway of the Italy energy system until the year 2050, referring to a ‘‘business as usual’’ (BAU) scenario, that reflects actual national policies and trends in energy consumption.

The results show that the primary energy consumption of Italy increases constantly from year 2005 until 2050. There is a remarkable increase of natural gas and coal that are both imported, as well as oil products, pointing out the structural weakness as concerns the national energy security of supply.

Final energy consumption is characterized by a growing demand of electricity by almost all sectors, fulfilled by more efficient thermal plants, co-generation and, many renewable power plants (among which hydro are still prevailing) in line with the national policies. Consumption is increasing for industry, commercial, agriculture and transport but not for residential that, on the contrary, shows a declining trend.

In the transport sector there is still a high consumption of oil products, but it can be noted also an increasing consumption of biofuels according to the national directives.

Although the development of the electricity sector and a larger use of renewable, the emissions of CO_2 increase 24% respect to the base-year value, with a maximum of 511 Mtonnes in 2050, reflecting the still high consumption of oil products.

Next steps will deal with the analysis of some policy scenarios, in agreement with those planned for the Pan-European model, addressing environmental issues linked to energy use, such as Post-Kyoto climate and air quality policies, as well as energy policies aiming at reducing the EU-dependency on energy imports.

In this direction, future improvements of the model will focus mainly on the characterisation of air emissions, introducing further emission factors for GHGs other than CO_2 and for local air pollutants (CO, SO_2, NO_x, PM10, PM2.5, VOC).

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